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ANALYSIS OF RAIL GUN BORE RESIDUE

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (weh)

A technique for analyzing the residue left-in bore after firing a rail gun has been devised. The technique is based on nuclear backscattering of deuterons from residue collected on a clean beryllium disk. The disk was embedded in one of the insulating sections of the rail gun barrel where it was exposed to residue-producing gases during a firing, then removed from the barrel for backscattering analysis. An energy spectrum of backscattered deuterons was obtained by bombarding the disk with a 1.0 MeV deuteron beam from a Van de Graaff (con't)

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) accelerator and monitoring a backward scattering angle with a charged particle detector. Computational techniques were used to quantitatively determine from the observed backscattered spectrum amounts of each element deposited on the surface.

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I. INTRODUCTION

One of the critical unknowns in the development of repetitively fired electromagnetic rail guns, along with pulsed power switching, is the progressive degradation of the inner bore surface. Virtually all rail gun firings leave a black powdery residue on the inner surfaces of the bore after a single shot. Analyses of this residue have been reported by various experimenters utilizing a variety of techniques.[1-3] Typically these techniques involve removal of the residue from a bore surface prior to analysis, a process which raises the question of whether or not a representative sample was actually taken. Reported analyses include chemical and atomic methods, both of which are sensitive to the chemical form (or forms) of each of the elemental constituents of the residue.

Sensitivity to the chemical form of each of the residue constituents leads to uncertainty in the completeness of the analysis. It is doubtful that a careful search for every possible chemical form possible in the residue could be performed. Nuclear backscattering is, however, sensitive only to the masses of the target and bombarding nuclei. Residue analysis by a nuclear backscattering technique is therefore completely insensitive to the chemical composition of the residue. A numerical method of determining the composition of surface layers from nuclear backscattering data has been developed and documented by Niiler, et al.[4] This method has been successfully used for a variety of applications including substrate-plating interface studies,[5] surface erosion effects [6] and elemental analysis of refractory materials.

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[1] *C. A. L. Westerdahl, J. Pinto, G. L. Ferrentino, D. N. Scherbarth, and T. Gora, "Large Rail Gun Residue Material Analyzed by X-Ray Photoelectron Spectroscopy," IEEE Trans. on Mag. Vol. Mag-19, No 1, January 1983, p 53.*

[2] *A. J. Bedford, "Rail Damage in a Small Calibre Rail-Gun," 2nd Symposium on Electromagnetic Launch Technology, Boston, MA, October 10-13, 1983.*

[3] *D. P. Bauer, J. P. Barber, and W. R. Kerslake, "Investigation of the Residue in an Electric Gun Employing a Plasma Armature," 2nd Symposium on Electromagnetic Launch Technology, Boston, MA, October 10-12, 1983.*

[4] *A. Niiler, R. Birkmire and J. Gerrits "PROFILE: A General Code for Fitting Ion Beam Analysis Spectra," BRL Report ARBRL-TR-02233, April 1980. ADA-084 984, Available from National Technical Information Service, Springfield, VA 22161.*

[5] *William F. Henshaw, John R. White and Andrus Niiler, "Ion Plating of Chrome Coating in Tubes," BRL Report ARBRL-TR-02430, October 1982. ADA-121 266, Available from National Technical Information Service, Springfield, VA 22161.*

[6] *A. Niiler, R. Birkmire and S. E. Caldwell "The Effects of Propellant Burn on the Surface Composition of Gun Steel," BRL Report ARBRL-TR-02380, November 1981. Available from National Technical Information Service, Springfield, VA 22161. AD A108 292.*

In this report we describe a technique we have developed and implemented for analysis of the post firing residue of a rail gun. This technique involves the collection of residue on an inner bore surface insert which is removed for nuclear backscattering analysis. The results from one experiment performed at the BRL one meter rail gun[7] are presented and discussed.

II. EXPERIMENT

The BRL one meter rail gun,[7] which utilizes arc drive, is typical of many such devices in that after a firing all the inner bore surfaces are covered with a black, soot-like residue. This residue is presumed to be the remnant or result of an arc which carried a current on the order of 100,000 amperes and sustained Lorentz pressures on the order of 10's of MPa as it accelerated a projectile down the bore. In laboratory devices this residue creates only a small inconvenience, but for future, fieldable systems, any such coating on insulator surfaces must be well understood. The first step toward a complete description of this soot is collection and analysis. To collect a sample of the residue, a 3mm (1/8 inch) hole was drilled through one of the insulating sections of the rail gun barrel. A 10mm (3/8 inch) diameter by 3mm (1/8 inch) thick beryllium disk was affixed on the outside of the insulating section, completely covering the hole. Figure 1 shows a cutaway view of the inner barrel assembly with the disk in place. Copper bars comprised the upper and lower conducting sections of the barrel while tee shaped, fibered epoxy members formed the opposing insulating sections of the barrel. During the firing, the beryllium disk was supported so that hydrostatic pressure from the arc would not displace it. The disk was located 52cm from the point at which the arc was initiated and 40cm from the muzzle of the gun. The sample site was chosen to be mid-bore, where visual inspection suggested that the soot thickness was representative of the average deposition throughout the entire bore surface. The use of a removable disk of beryllium inserted as part of the inner bore surface should guarantee that the composition of the collected residue is as representative as possible. Note, however, that turbulence and deposition in the passage linking the bore and insert may affect the residue composition. The parameters for the firing were as follows:

- Peak Arc Current 180,000 A
- Arc Current at collection site 30,000 A
- Arc initiator 0.10 gram aluminum foil
- Final projectile velocity 1.4 km/s
- Barrel initially at atmosphere pressure
- 2.4 gram lexan projectile with neoprene rear seal
- Closed breech

After the firing, the usual rail gun residue was observed from the muzzle end of the bore towards the breech over a distance of about 70cm. The soot was visible not only on the inner surfaces, but also in the joints

[7] *K. A. Jamison and Henry S. Burden, "A Laboratory Arc Driven Rail Gun," BRL Report ARBRL-TR-02502, June 1983. ADA 131 153, Available from National Technical Information Service, Springfield, VA 22161.*

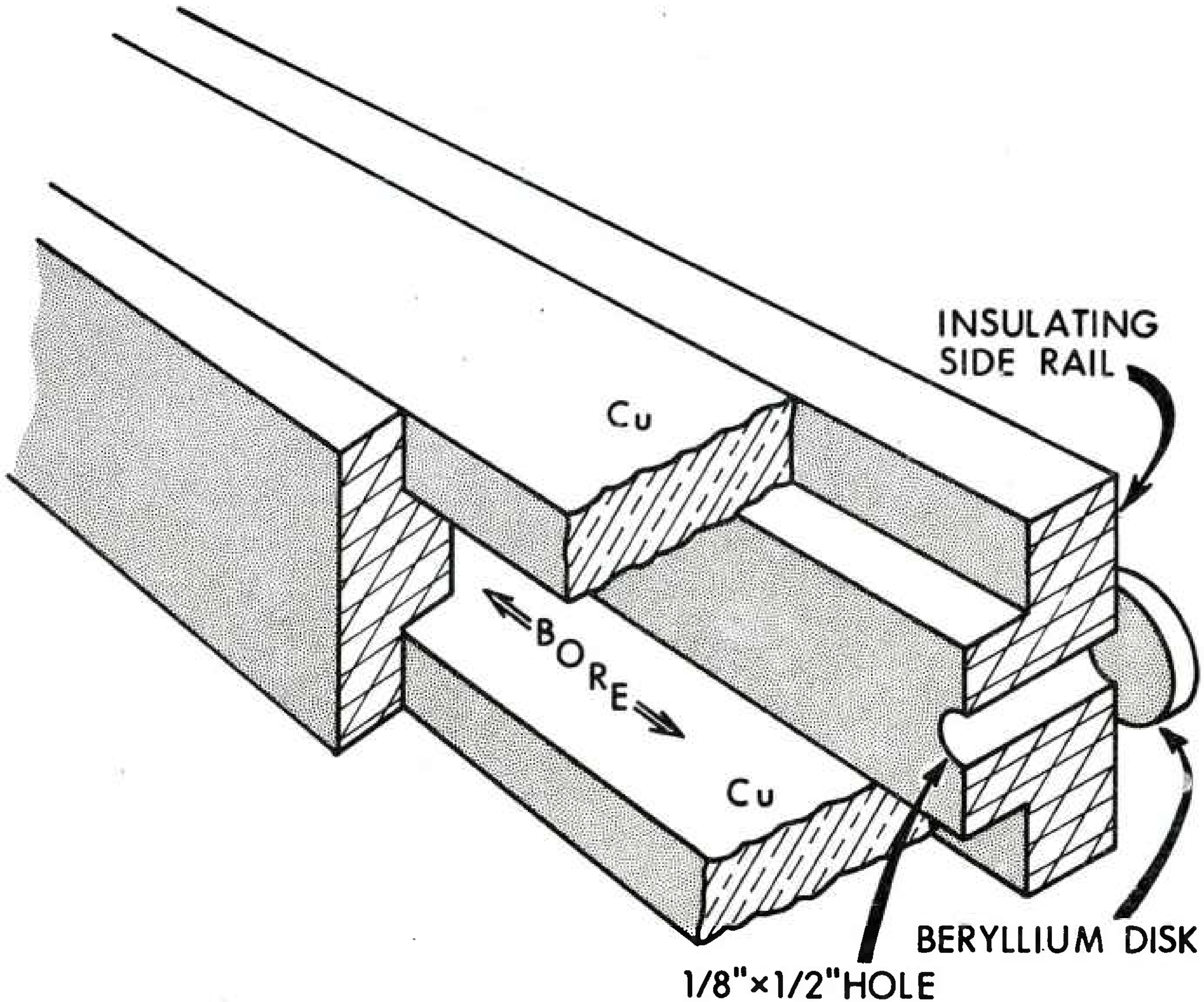

Figure 1. Cutaway view of rail gun barrel showing residue collection site

between the copper and insulating rails where high pressure forced the residue as the projectile was accelerating. Also clearly visible was a spot where soot was deposited on the beryllium disk.

The disk was removed from the rail assembly and placed in a vacuum chamber along with a clean (washed with acetone) beryllium disk. Next, a beam of 1.0 MeV deuterons was focussed in turn on each disk, normal to the face. A silicon surface barrier detector located on a line 20 degrees off the normal detected the energies of the 160 degree backscattered deuterons. Pulses from the detector were preamplified, amplified, and recorded by a pulse height analyzer, resulting in a distribution of backscattered flux versus energy of the backscattered deuteron. The distributions recorded for the clean beryllium disk and for the one used for residue collection are shown in Figure 2 and Figure 3 respectively. The observed structure is delineated with the causative elements. Since the energy of the deuteron backscattered by a surface nucleus is dependent only on its precollision energy and the mass of the nucleus with which it collides, easy identification of spectral features which result from surface collisions may be obtained. As the beam of deutrons traverses the residue, however, it loses energy and the precollision energy becomes progressively smaller. The scattered deuterons, too, lose energy as they exit the material being analyzed. The net result of these effects is the series of wedge shaped structures which extend to lower energies from the element labels. The ledge labeled Be results from deuterons which have been backscattered from the beryllium disk beneath the residue. The very small peaks labeled O and C in Figure 2 are probably the result of the acetone washing and the carbon represents less than 0.03 percent of the surface probed. The slight difference in the level to the left and right of the oxygen peak in Figure 2 is a result of the composition of the insert which is two percent BeO. A one percent oxygen content accurately models this spectral feature.

Figure 3 displays easily visible features resulting from beryllium, carbon, oxygen, aluminum and copper. While the copper wedge is largest, it must be remembered that backscattering cross sections vary like as the square of the nuclear charge of the scattering center. A consequence of the charge dependence of the cross section is that copper actually accounts for the smallest fraction of any of the residue constituents.

It is of some concern that no easily identifiable structure is observed for nitrogen which is present in both the insulating sections of the bore and the rear seal on the projectile. Other portions of the spectrum not shown in Figure 3 verify the presence of small amounts of nitrogen. If large amounts of nitrogen were present in the residue some structure should be visible between the wedges labeled C and O. One possible explanation is that nitrogen forms volatile compounds which do not plate out as residue.

III. ANALYSIS

For quantitive analysis of the amount of each of the residue constituents, one must turn to rather sophisticated numerical techniques as may be found in computer codes such as "PROFILE"[3] which was developed to give atomic densities from backscattered data as presented here. The program essentially sections the surface into layers as defined by the user and returns the atomic

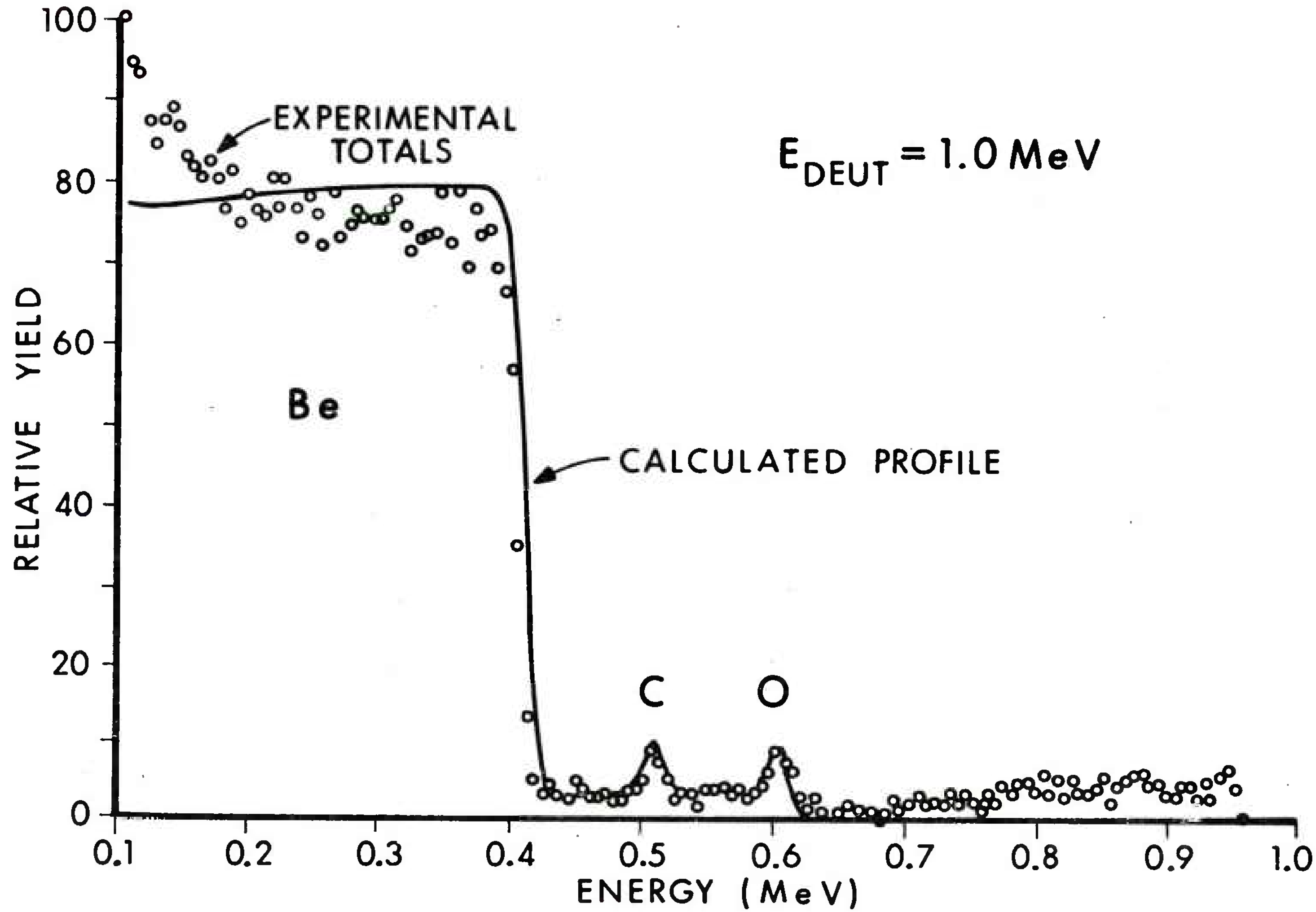

Figure 2. Backscatter spectrum of 1.0 MeV deuterons impacting clean beryllium disk

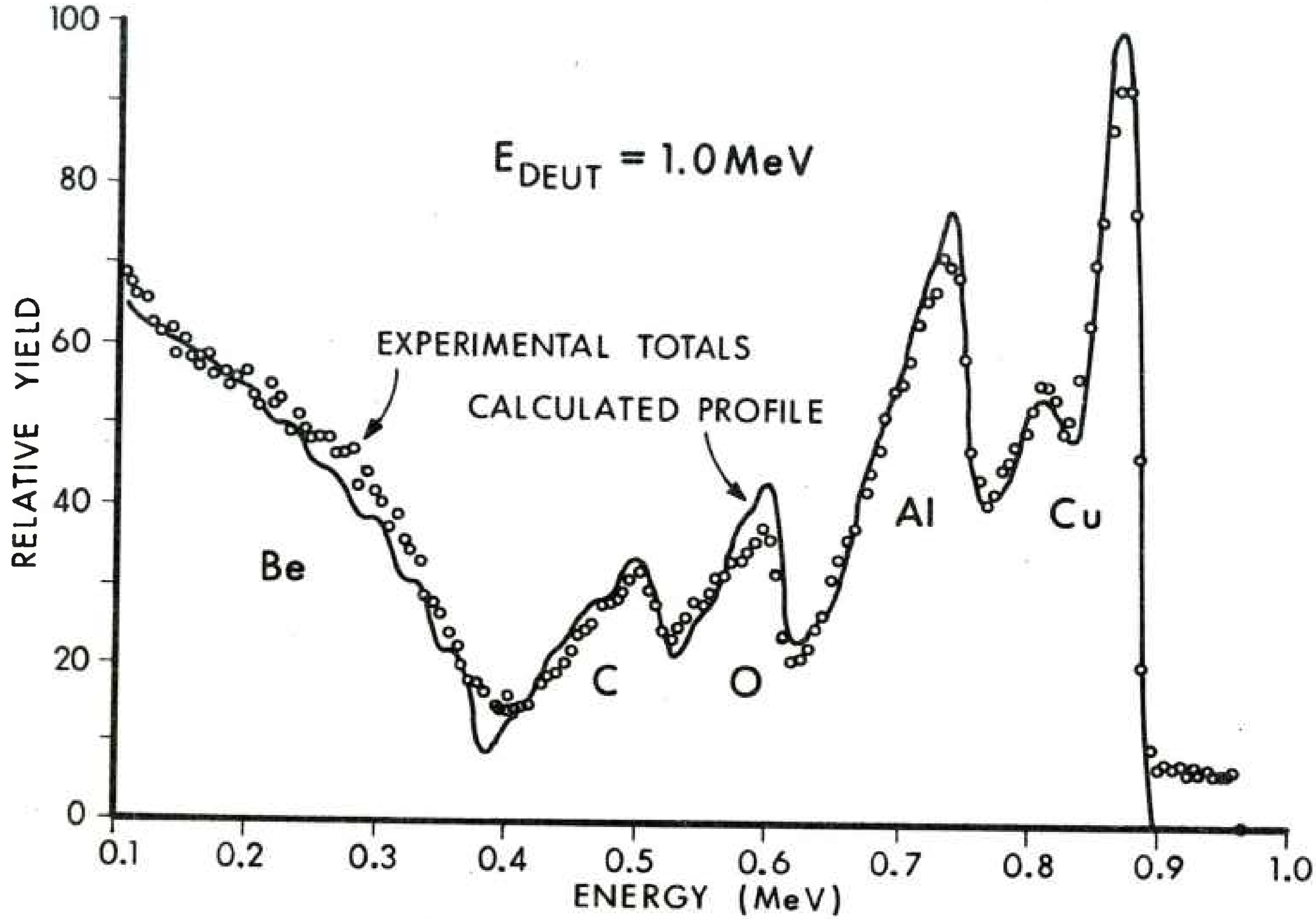

Figure 3. Backscatter spectrum of 1.0 MeV deuterons impacting rail gun residue collected on beryllium disk

percentage for each specified constituent, layer by layer. The specified inputs to PROFILE were the spectrum of Figure 3, a layer thickness of 40 $\mu g/cm^2$, and the constituents copper, aluminum, oxygen, carbon, beryllium and hydrogen. The output of PROFILE is shown in Table 1 and is displayed graphically in Figure 4. Figure 4 omits the values of beryllium, since it is not part of the residue, and the values for H because they have large uncertainties. Depth into the surface is read from left to right; conversely, the time sequence of the "plating out" of the residue is read from right to left. The percentage values for C, O, and Al are decreasing or constant as one probes deeper into the residue. The atomic percentage of copper decreases, increases and then decreases which might indicate temporal changes in the gases plating out to form the residue. While this sample does not have the statistical certainty to define these temporal changes, the technique described here does have the potential for analyzing significant temporal changes in plating. To extend the analysis in this area would require knowledge about diffusion, the chemistry of the residue, and the thermal history of the collection site. These factors are beyond the scope of this report.

The values in Table 1 and Figure 4 are number densities and must be multiplied by the corresponding atomic weight if mass comparisons are to be made.

TABLE I

Percentage Relative Atomic Concentration vs Depth

Depth ($\mu g/cm^2$)	Carbon (%)	Oxygen (%)	Aluminum (%)	Copper (%)	Hydrogen* (%)	Beryllium (%)
40	10.0	7.4	4.5	2.0	76	0
80	10.0	7.2	4.5	1.1	52	25
120	9.0	7.0	4.5	1.4	32	46
160	7.0	5.2	3.4	1.1	21	62
200	4.0	4.0	2.7	1.0	14	74
240	2.0	3.0	1.6	.6	12	80
280	1.0	1.0	.5	.3	11	86
320	0	0	0	0	10	90
360	0	0	0	0	5	95
400	0	0	0	0	0	100

*Values for hydrogen must be regarded as estimates only.

The depth scale is given in terms of areal density, in units of $\mu g/cm$. The more logical measure of thickness cannot be used since the density of the soot as it lies on the Be surface is neither constant nor determinable. The values tabulated for hydrogen have by far the greatest uncertainty as no direct spectral structure can be detected. Second order effects in the spectrum do imply extra material on the surface and hydrogen was the only choice since any element heavier than beryllium would have exhibited spectral features. The resulting number density of hydrogen cannot be very exact but is included in Table 1 as a matter of completeness.

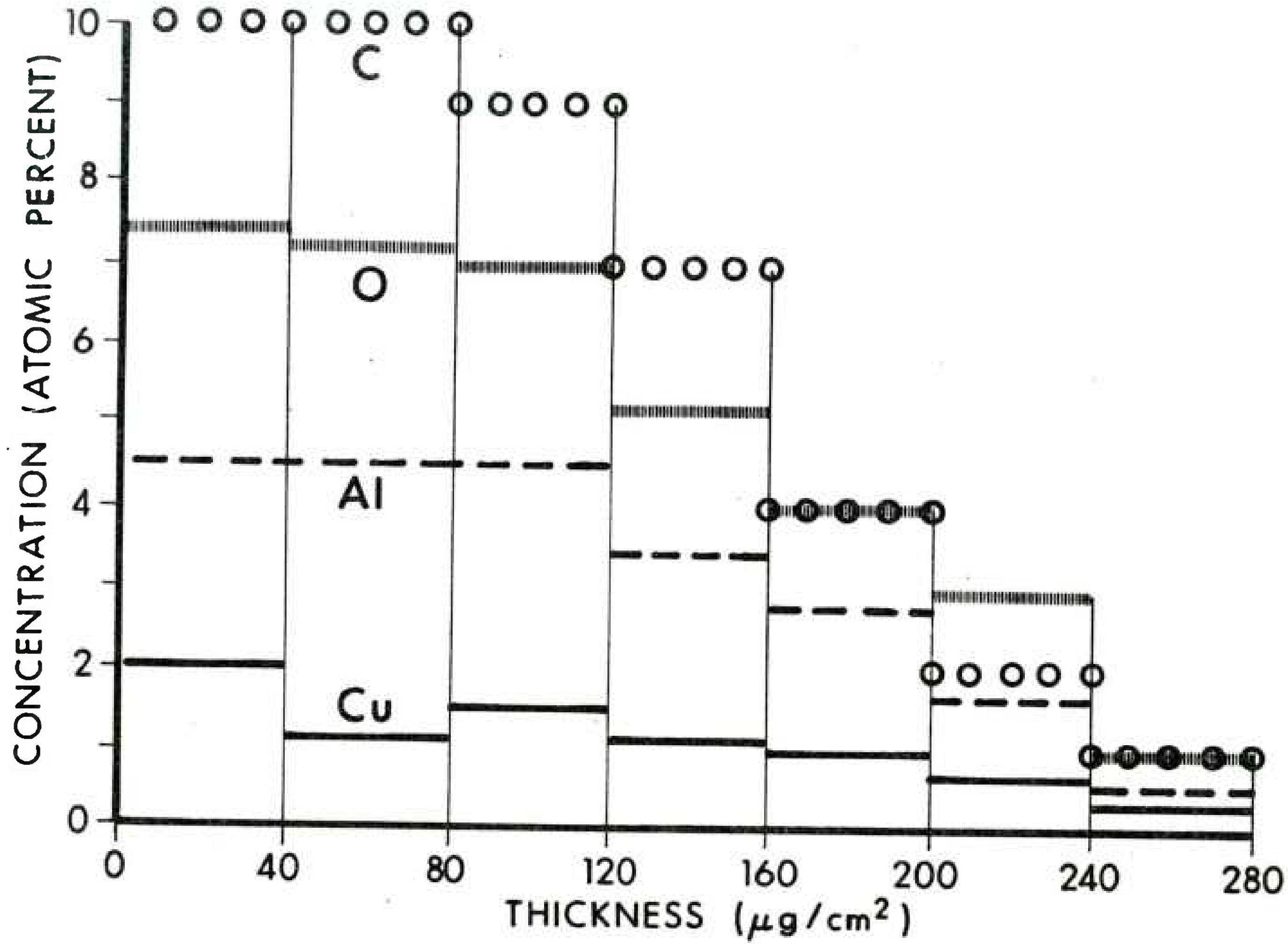

Figure 4. Concentration versus depth profile for elements identified in rail gun residue

It is useful to compare the relative number of atoms in the total collected residue. The copper undoubtedly originated in the rails, the aluminum in the arc initiator foil, and the carbon and oxygen in either the insulating side rails or the projectile. With copper as the base line, the following atomic ratios were found.

0	Al/Cu	3.0 $\pm$ 0.6
0	O/Cu	4.7 $\pm$ .8
0	C/Cu	6.3 $\pm$ 1.0

Even if the hydrogen results are excluded, Cu from the rails accounts for less than 7 percent of the residue. If hydrogen is included, the fractional number of copper atoms in the residue is only three percent.

To compare the relative mass of each of the constituents, the previously stated atomic percentages must be converted for each individual layer. This conversion is tabulated in Table 2; again, hydrogen and beryllium are not included. The relative mass abundance of each of the elements listed in Table 2 is nearly equal, owing to the wide variance in atomic weight. The totals represent the total mass per unit area of each element deposited on the beryllium insert.

TABLE II

Areal Mass Density Of Residue Constituents By Layer

Layer Range ($\mu g/cm^2$)	Carbon ($\mu g/cm^2$)	Oxygen ($\mu g/cm^2$)	Aluminum ($\mu g/cm^2$)	Copper ($\mu g/cm^2$)
0-40	3.8	3.8	3.9	4.0
40-80	4.1	3.9	4.1	2.4
80-120	3.7	3.8	4.2	3.0
120-160	3.1	3.0	3.3	2.5
160-200	1.8	2.4	2.8	2.4
200-240	1.0	1.9	1.7	1.5
240-280	.5	.7	.6	.8
Total, all layers	18.0	19.6	20.6	16.8

The sample site was chosen to be representative of the average deposition throughout the entire bore surface. If effects of the recessed configuration of the collection scheme (see Figure 1) may be ignored, order of magnitude estimates of the total mass of residue plated onto the 500 cm^2 inner bore surface can be determined. We find, by multiplying the areal density by the bore surface area, 0.010 and 0.008 grams of Al and Cu deposited respectively. The aluminum mass accounts for 1/10 of the mass of the arc initiator foil and is reasonable owing to the fact that some residue escapes the bore after firing and some aluminum remains at the point of arc initiation. The small copper mass might indicate that very little erosion of the conducting rails has occurred. However, the material loss is likely to be highly nonuniform, most of it occurring at the arc initiation site. We are in the process of measuring the erosion of copper by a nuclear activation method which will provide sub-micron resolution of the wear due to plasma arc armatures in rail guns.

IV. CONCLUSION

We have developed and implemented a technique for analysis of the post firing residue of a rail gun. This technique involves the collection of residue on an inner bore surface insert which is removed for nuclear backscattering analysis. The method is sensitive only to the atomic mass of the deposited constituents, not to their chemical composition or atomic state. The result of one experiment done with copper rails, melamine insulators, and an aluminum foil arc initiator shows relatively few copper atoms in the residue. Carbon comprises the largest percentage of atomic species in the residue, followed by oxygen, aluminum and copper. There was secondary evidence of hydrogen, but with this technique quantitative results for hydrogen concentrations were not possible.

More spectral detail, resulting from better energy dispersion over the atomic mass range observed here, is possible with helium backscattering. This is due to both the interaction kinematics and the higher specific energy loss of helium ions. As a further point of interest, it might be possible to unfold the sequence of constituent ratios from an undisturbed residue deposit.

The authors are performing further experiments of this type in the large rail gun accelerator facility at Large Caliber Weapons Systems Laboratory, Dover, New Jersey.

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6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: ______________________________

Telephone Number: ______________________________

Organization Address: ______________________________

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